Left ventricular atrioventricular plane displacement: an echocardiographic technique for rapid assessment of prognosis in heart failure

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Abstract

Objective—To assess the prognostic value of atrioventricular plane displacement in heart failure patients.

Design—Patients were followed prospectively for one year after atrioventricular plane displacement determination.

Setting—Malmö University Hospital, with a primary catchment area of 250 000 inhabitants.

Patients—181 patients with a clinical diagnosis of heart failure; age 75·7 (SD 5·2) years, duration of heart failure 2·7 (5·7) years; 100 men, 81 women.

Main outcome measures—Mortality in relation to atrioventricular plane displacement.

Results—Total mortality was 22·7% (41/181), and was highly significantly (P = 0·001) related to atrioventricular plane displacement. Mortality within prospectively defined categories of displacement was: ≥ 10·0 mm, 0% (0/19); 8·2 to 9·9 mm, 10·3% (3/29); 6·4 to 8·1 mm, 19·4% (12/62); and < 6·4 mm, 36·6% (26/71). The groups were similar in age, sex, angiotensin converting enzyme inhibitor and β blocker treatment, and cause and duration of heart failure.

Conclusions—Mortality in heart failure is strongly related to atrioventricular plane displacement.

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Keywords: atrioventricular plane displacement; echocardiography; prognosis; heart failure

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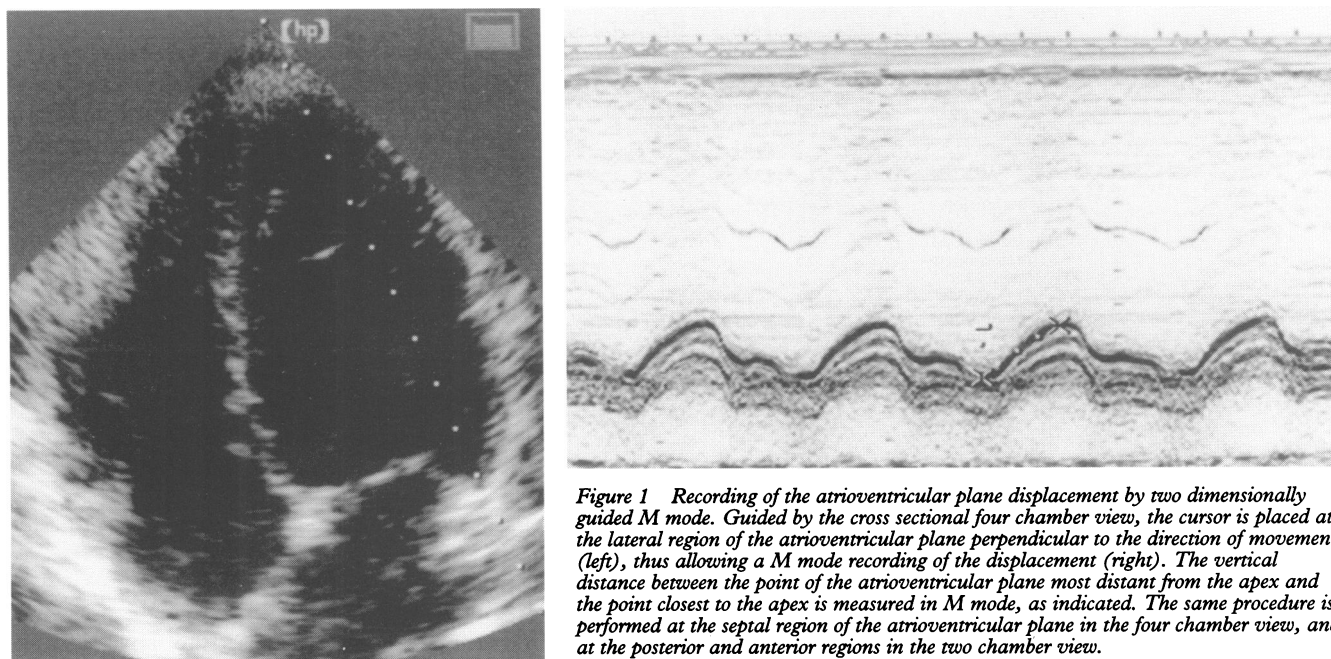S-205 02 Malmö, Sweden.

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The prognosis of patients with chronic heart failure is related to the degree of functional impairment of the left ventricle.[1-5] Left ventricular systolic function is usually expressed as ejection fraction and is most commonly measured by radionuclide ventriculography, contrast cineangiography, or echocardiography. Echocardiography is less complicated, expensive, and time consuming than either radionuclide ventriculography or ventricular angiography. Furthermore, ventricular angiography has the disadvantage that left ventricular ejection fraction may be overestimated because of stress to the patient, or underestimated because of the negative inotropic action of the contrast medium.[6]

Several echocardiographic techniques can be applied to evaluate left ventricular systolic function. The fractional shortening and Teichholz techniques are not reliable when left ventricular contraction is asymmetrical.[7-9] Cross sectional echocardiography tolerates asymmetry but requires good image quality for adequate tracing of the endocardial borders,[10-12] which is not always obtainable. Some investigators have reported that the limits of agreement between left ventricular ejection fraction determined by cross sectional echocardiography, on the one hand, and by radionuclide ventriculography or contrast cineangiography on the other, are quite disparate.[13 14] Others have shown that cross sectional echocardiography compares well with radionuclide ventriculography.[15 16] It has been reported that cross sectional echocardiographic assessment of regional wall motion correlates well with haemodynamic status and is reliable and reproducible.[17 18] However, it is time consuming and requires experienced investigators as well as good image quality.[17 18]

The left ventricular pump function has traditionally been attributed mainly to the circumferentially orientated myocardial fibres.[19] However, the complexity of myocardial fibre orientation and the importance of longitudinal myocardial fibres was described in man in the early 1980s.[20] The significance of longitudinal fibres for left ventricular ejection has since been further emphasised.[21-29] The epicardial surface of the heart remains practically immobile during the cardiac cycle,[22] and normal left ventricular ejection cannot take place unless the atrioventricular plane moves. During cardiac systole the atrioventricular plane moves towards the apex as a result of contraction of longitudinal fibres,[22] and during diastole it moves away from the apex. Since the distance between the apex of the heart and the chest surface is constant during the cardiac cycle,[21 22 30] the atrioventricular plane displacement measured from the surface of the thorax, using transthoracic two dimensionally guided M mode echocardiography (fig 1), equals the intraventricular displacement.[25] Left ventricular atrioventricular plane displacement determined in this way has been shown to correlate well with left ventricular ejection fraction calculated by cross sectional echocardiography using the area-length method ($r = 0·96$), left ventricular wall motion index ($r = 0·91$), radionuclide ventriculography ($r = 0·82$ to $0·87$), and contrast cineangiography ($r = 0·89$).[26-29] Atrioventricular plane displacement reflects global left ventricular function despite left ventricular asymmetry, since it is determined in four different regions of the left ventricle—the septal, lateral, posterior, and

Figure 1 *Recording of the atrioventricular plane displacement by two dimensionally guided M mode. Guided by the cross sectional four chamber view, the cursor is placed at the lateral region of the atrioventricular plane perpendicular to the direction of movement (left), thus allowing a M mode recording of the displacement (right). The vertical distance between the point of the atrioventricular plane most distant from the apex and the point closest to the apex is measured in M mode, as indicated. The same procedure is performed at the septal region of the atrioventricular plane in the four chamber view, and at the posterior and anterior regions in the two chamber view.*

anterior regions—and since it evaluates the total shortening along the left ventricular long axis in the respective regions. It demands very little of image quality as the atrioventricular plane is highly echogenic, and the examination is rapidly performed. However, the shortening of the left ventricular long axis, that is, the shift of the atrioventricular plane, is a different expression of function in comparison with the relation between stroke volume and end diastolic volume. Indeed, the limits of agreement between left ventricular ejection fraction and atrioventricular plane displacement are not close enough for these two measurements to be interchangeable.[26-29] Thus there is reason to question whether atrioventricular plane displacement provides the same prognostic information as left ventricular ejection fraction, and it is therefore imperative to evaluate the prognostic value of atrioventricular plane displacement determination before recommending that it be generally used.

The aim of this study was to investigate whether echocardiographic determination of atrioventricular plane displacement would provide prognostic information in patients with chronic heart failure, and to assess any relations between atrioventricular plane displacement and clinical findings, including medication.

Methods

PATIENTS
All patients between 65 and 84 years of age who were admitted from the emergency room at Malmö University Hospital because of symptoms suggestive of heart failure were screened for inclusion in the study between December 1991 and October 1993. Patients were considered eligible when admitted to the departments of internal medicine or cardiology with the diagnosis of heart failure, and showing at least one of the following clinical signs of heart failure: pulmonary rales, peripheral oedema, third heart sound, pulmonary

congestion on chest *x* ray. Patients were excluded if the following predefined exclusion criteria were present: follow up difficulties were foreseen (for example, patients not residing permanently in Malmö, non-Swedish speaking, reading or writing problems, drug or alcohol abuse, significant psychiatric disease, etc); concomitant serious disease that could influence morbidity and mortality; informed consent was not received; enrolment in another clinical trial; the patient's treating physician found participation unsuitable; death shortly after admission before the study echocardiographic examination could be performed. Two patients were not examined by echocardiography for administrative reasons. Eventually 181 patients were included in the study. Baseline characteristics are shown in table 1.

ECHOCARDIOGRAPHIC EXAMINATION
A cross sectional echocardiographic examination was performed as soon after inclusion as the patient's condition allowed, by either of two investigators blinded to the results of other examinations. The equipment used was a Hewlett-Packard (Andover, Massachusetts, USA) Sonos 1000 echocardiography system and a 2·5 MHz transducer. An apical view was obtained during silent respiration or end expiratory apnoea with the patient in a left lateral recumbent position. Left ventricular atrioventricular plane displacement was evaluated in two-dimensionally guided M mode, in the four and two chamber views (fig 1). The regional displacement (mm) was the distance covered by the atrioventricular plane between the position most remote from the apex (corresponding to the onset of contraction) and the location closest to the apex (corresponding to the end of contraction, including any postejection shortening), that is, the full extent of the displacement. It was measured in the septal, lateral, posterior, and anterior regions, and was calculated from an average of four measurements in patients with regular rhythm,

Table 1   Baseline characteristics in relation to atrioventricular plane displacement

	Total (n = 181)	AVPD ≥ 10 mm (n = 19)	AVPD 8·2–9·9 mm (n = 29)	AVPD 6·4–8·1 mm (n = 62)	AVPD < 6·4 mm (n = 71)	P
Age (years) (SD)	75·7 (5·2)	73·3 (6·4)	76·2 (3·8)	76·1 (5·1)	75·7 (5·4)	NS
Females, n (%)	81 (45)	10 (53)	16 (55)	28 (45)	27 (38)	NS
Duration of HF (years) (SD)	2·5 (4·1)	1·8 (2·6)	1·9 (3·0)	1·9 (3·2)	3·4 (5·3)	NS
Cause of HF (%)						NS
Ischaemic	54	26	55	60	55	
Hypertension	12	11	14	13	10	
Valvar	8	26	7	2	10	
Idiopathic CM	1	0	3	0	1	
Undetermined	25	37	21	25	24	
Treatment (%)						
Oral diuretics	70	47	66	65	82	0·016
ACE inhibitors	22	11	28	15	28	NS
Long acting nitrates	33	26	34	29	38	NS
β blockers	9	11	14	11	6	NS
Digitalis	32	21	28	19	48	0·003
NYHA class (%)						NS
I	9	16	14	8	7	
II	25	26	24	24	27	
IIIa	35	32	48	35	30	
IIIb	27	26	10	26	35	
IV	4	0	4	7	1	

ACE, angiotensin converting enzyme; AVPD, atrioventricular plane displacement; CM, cardiomyopathy; HF, heart failure; NYHA, New York Heart Association.

and eight measurements in patients with irregular rhythm. The mean of the atrioventricular plane displacement in the four regions was calculated. In our laboratory the mean interindividual variability between the two investigators in this study (examining each patient one after another) was 4·8% (atrioventricular plane displacement difference range 0 to 1·2 mm) in a series of 53 consecutive patients with a mean displacement of 7·8 mm (range 3·3 to 15·5 mm). The average time spent on a determination of atrioventricular plane displacement in our laboratory is approximately five minutes.

Left ventricular ejection fraction (LVEF) can be calculated from the regression equation, in Alam et al,[26] describing the relation between the ejection fraction, determined by radionuclide ventriculography, and echocardiographically assessed atrioventricular plane displacement:

$$LVEF = (5·5 \times mean \ atrioventricular \ plane \ displacement) - 5$$

Thus the cut off values used in our study are explained: 10·0 mm = LVEF 0·50; 9·1 mm = LVEF 0·45; 8·2 mm = LVEF 0·40; 7·3 mm = LVEF 0·35; 6·4 mm = LVEF 0·30. The average atrioventricular plane displacement in elderly controls is 14·5 to 15 mm, and a mean displacement ≥ 10·0 mm is usually considered normal.[25 28]

The echocardiograms were also reviewed in order to determine whether an adequate endocardial tracing in the apical view could be performed for measurement of left ventricular ejection fraction. Image quality was graded as: (1) poor, that is, less than 50% of the endocardium was visualised and no tracing could be performed; (2) mediocre, that is, 50–90% of the endocardium was visualised and a somewhat unreliable tracing could be performed; or (3) good, that is, at least 90% of the endocardium was visualised and an adequate, reliable tracing could be performed.

In order not to influence the treatment of the patients, and thereby possibly the prognosis, the results of the echocardiographic examinations were not disclosed to any persons involved in the care of the patients. Clinical echocardiographic examinations could be performed according to routine indications.

CLINICAL ASSESSMENT
A clinical examination was performed and noted in the patient file at entry to the emergency room. Based on the patient's history and referring to stable conditions before worsening heart failure causing admission to hospital, patients were also classified according to the New York Heart Association classification (NYHA I, II, IIIa, IIIb, or IV).

FOLLOW UP
All patients were invited to a one year clinical follow up visit. Patients not attending the follow up visit were searched for in a central database, were all deaths in our community are registered. All deaths were verified by death certificates. Mortality was thus reliably assessed.

STATISTICS
Differences between two groups regarding continuous variables were tested by the unpaired t test, and for multiple group comparisons the Kruskal-Wallis test was performed. Regression analysis and analysis of variance was used to analyse correlations between two continuous variables. To assess differences between groups with respect to nominal variables the χ^2 (for more than 2 × 2) and Fisher's exact (for 2 × 2) tests were performed. Data are expressed as mean (SD), and a P value < 0·05 was considered significant.

Results
ASSESSMENT RATE FOR ATRIOVENTRICULAR PLANE DISPLACEMENT V ENDOCARDIAL TRACING
Left ventricular atrioventricular plane displacement was readily determined in all patients. Image quality was judged to allow a completely reliable tracing of endocardial bor-

Table 2 One year mortality in patients with an atrioventricular plane displacement (AVPD) below and above the respective cut off values

Cut off value (mm)	Above cut off		Below cut off		
	n	Mortality (%)	n	Mortality (%)	P
10·0	19	0 (0)	162	41 (25·3)	0·008
9·1	31	1 (3·2)	150	40 (26·7)	0·004
8·2	48	3 (6·2)	133	38 (28·6)	0·001
7·3	73	10 (13·7)	108	31 (28·7)	0·019
6·4	110	15 (13·6)	71	26 (36·6)	< 0·001

An AVPD of 10·0 mm corresponds to an ejection fraction of 0·50, 9·1 mm to 0·45, 8·2 mm to 0·40, 7·3 mm to 0·35, and 6·4 mm to 0·30.

ders (grade 3) for measurement of left ventricular ejection fraction in 29/181 patients (16%), permitted a suboptimal and somewhat unreliable tracing (grade 2) in 111 (61%), and was too poor for tracing (grade 1) in 41 patients (23%).

ATRIOVENTRICULAR PLANE DISPLACEMENT IN RELATION TO MORTALITY

Mean left ventricular atrioventricular plane displacement in all patients (n = 181) was 7·1 (2·2) mm. It was significantly lower in the patients that died during the one year follow up (n = 41, 22·7%) than in the survivors, at 5·8 (1·7) mm v 7·4 (2·2) mm, P < 0·0001. Mortality in patients with a displacement ⩾ 10·0 mm (n = 19, 10·5%) was 0%, while it was 25·3% (41/162) in patients with a displacement of < 10·0 mm (P = 0·008). The corresponding figures for the other cut off values are shown in table 2. Thus by measuring left ventricular atrioventricular plane displacement it was possible to distinguish patients with a high as well as those with a low probability of dying during one year. Irrespective of the cut off value chosen, there was a significant difference in displacement between survivors and non-survivors (table 3). With decreasing atrioventricular plane displacement, mortality increased (fig 2). In patients with a displacement ⩾ 10·0 mm it was 0% (0/19); with a displacement 8·2 to 9·9 mm it was 10·3% (3/29); with a displacement 6·4 to 8·1 mm it was 19·4% (12/62); and with a displacement of < 6·4 mm it was 36·6% (26/71) (P = 0·001, fig 3). The four groups were similar as regards age, sex, baseline angiotensin converting enzyme (ACE) inhibitor and β blocker treatment, and cause and duration of heart failure. There was a significant (P = 0·003) between group difference with respect to digitalis treatment, more patients being treated with digitalis at baseline in the group with an atrioventricular plane displacement of < 6·4 mm than in the other three groups (table 1). Among the patients who survived and

attended the one year control visit (n = 121), there were no differences between the four displacement groups with regard to treatment with ACE inhibitors (taken by 60% of the patients), β blockers (4%), diuretics (98%), long acting nitrates (38%), or digitalis (50%).

ATRIOVENTRICULAR PLANE DISPLACEMENT IN RELATION TO CLINICAL FINDINGS AND TREATMENT

There were no significant differences in atrioventricular plane displacement in relation to cause of heart failure (ischaemic heart disease 6·8 (1·8) mm; hypertension 7·3 (2·8) mm; valvar disease 8·0 (3·5) mm; idiopathic cardiomyopathy 7·5 (3·2) mm; undetermined 7·4 (2·2) mm), nor with regard to NYHA class (table 1).

Atrioventricular plane displacement did not differ significantly between patients treated
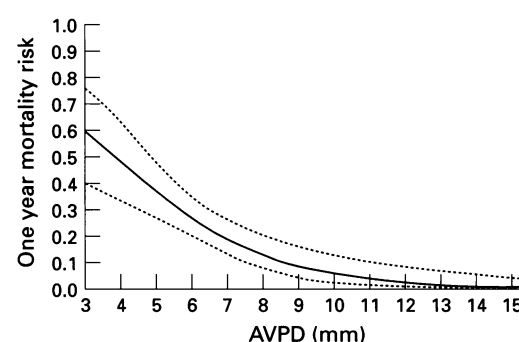
Figure 2 One year mortality risk in relation to left ventricular atrioventricular plane displacement (AVPD), by logistic regression analysis. Dotted lines show 95% confidence interval.

Table 3 Mean atrioventricular plane displacement (AVPD) in patients with values below the respective cut off limits, comparing survivors and patients who died during one year follow up

Cut off value	AVPD (mm) in survivors, mean (SD)	(n)	AVPD (mm) in non-survivors, mean (SD)	(n)	P
10·0	6·8 (1·6)	(121)	5·8 (1·7)	(41)	< 0·001
9·1	6·6 (1·4)	(110)	5·7 (1·6)	(40)	0·001
8·2	6·2 (1·3)	(95)	5·5 (1·5)	(38)	0·006
7·3	5·9 (1·1)	(77)	5·0 (1·1)	(31)	< 0·001
6·4	5·2 (0·9)	(45)	4·6 (0·8)	(26)	0·017

An AVPD of 10·0 mm corresponds to an ejection fraction of 0·50, 9·1 mm to 0·45, 8·2 mm to 0·40, 7·3 mm to 0·35, and 6·4 mm to 0·30.
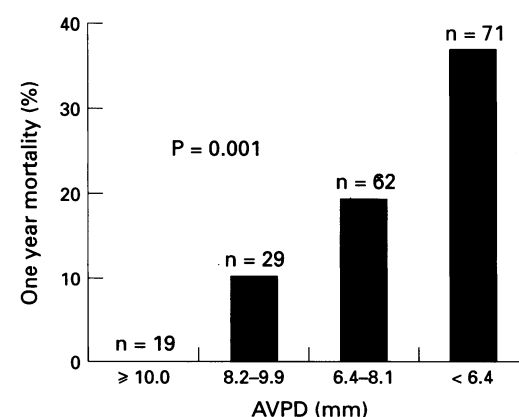
Figure 3 One year mortality in relation to left ventricular atrioventricular plane displacement (AVPD). Between group difference regarding mortality was tested by the Kruskal-Wallis test and is given in the figure.

with an ACE inhibitor (n = 39) and patients without ACE inhibitor treatment (n = 142) at baseline, or between males (n = 100) and females (n = 81).

None of the clinical signs pulmonary rales, dyspnoea, heart murmur, irregular heart rhythm, jugular venous distension, peripheral oedema, or peripheral cyanosis could be used to discriminate patients with respect to atrioventricular plane displacement. However, patients with a third heart sound at hospital entry (n = 8) had a significantly lower displacement than patients who were stated not to have a third heart sound (n = 13): 5·8 (2·3) v 7·8 (1·8) mm, P = 0·037. In the remaining 160 patients no data were given on the presence of a third heart sound on admission; atrioventricular plane displacement did not differ significantly between these 160 patients (7·1 (2·3) mm) and those with a third heart sound or those with established absence of a third heart sound. There was no correlation between atrioventricular plane displacement and pulse rate on admission, but there was a weak correlation between displacement and systolic blood pressure on admission (r = 0·192, P = 0·010). No such association was found with respect to diastolic blood pressure.

Discussion

This study shows for the first time that determination of left ventricular atrioventricular plane displacement provides strong prognostic information in heart failure patients. Mortality increased with decreasing displacement, and four of 10 patients with a displacement of less than 6·4 mm died within one year, while all patients with a displacement ≥ 10 mm survived. Thus determination of atrioventricular plane displacement is useful for assessment of prognosis in the individual heart failure patient, and not only in groups of patients. The results of this study are in agreement with previous findings regarding left ventricular ejection fraction and prognosis. However, our finding of a relation between atrioventricular plane displacement and prognosis is important because there was reason to question whether atrioventricular plane displacement would provide the same prognostic information as left ventricular ejection fraction. Thus atrioventricular plane displacement and left ventricular ejection fraction are quite different measurements of left ventricular function, though significantly correlated.[26-29] The systolic diameter reduction in the left ventricular short axis is considered to be due to contraction of circular fibres,[19] whereas the systolic left ventricular atrioventricular plane displacement has been shown to be the result of contraction of longitudinal fibres.[22]

Our results imply that determination of atrioventricular plane displacement may replace measurement of left ventricular ejection fraction for prognostic purposes. This could certainly save time and cost, since determination of atrioventricular plane displacement is rapidly performed (and consequently is relatively inexpensive), reproducible, rela-

tively quickly mastered, and demands little of image quality in comparison with standard techniques for this purpose. In this study atrioventricular plane displacement was readily determined in all patients, whereas assessment of left ventricular ejection fraction by traditional cross sectional echocardiography (requiring an endocardial trace) would only have been completely reliable in 16% of the patients, and not possible in 23%. In our laboratory we have evaluated left ventricular systolic function by determination of atrioventricular plane displacement in several thousand patients and have never failed to identify the four regions of the atrioventricular plane.

Heart failure patients require assessment of left ventricular systolic function for evaluation of prognosis and treatment selection. In Sweden alone, with almost nine million inhabitants, we estimate a yearly total of 30 000 new heart failure patients[31] requiring evaluation of left ventricular function; furthermore, in order to monitor the disease and evaluate treatment effects, every year a large group of the approximately 200 000 pre-existing heart failure patients requires assessment of left ventricular systolic function. Such a large number of determinations is expensive, and there is need for an uncomplicated, time and cost saving, but still reliable method for this purpose. Efforts have been made to find simple and inexpensive clinical predictors of left ventricular systolic function using, for instance, electrocardiographic and patient history data. Although there are reports of successful clinical indicators of preserved or disturbed left ventricular systolic function,[32 33] most have proved largely unsuccessful, especially when applied individually.[34-40] Neurohormones can be used to identify groups of patients with impaired left ventricular systolic function,[40-42] but for accurate determination of left ventricular ejection fraction in the individual patient an actual measurement is required.[40] Furthermore, echocardiography provides important information about cardiac dimensions and valvar function, and is recommended for routine use in the correct diagnosis of heart failure by the task force on heart failure of the European Society of Cardiology.[43] Since good clinical practice requires an echocardiographic examination in heart failure patients, it seems practical to evaluate left ventricular systolic function with an echocardiographic technique. Most traditional echocardiographic methods for determining left ventricular ejection fraction have disadvantages limiting their use.[7-14] Recently, assessment of left ventricular function by evaluation of the regional wall motion index was proved useful in a multicentre study.[18] However, this technique requires a great deal of experience for adequate interpretation, and is time consuming. Furthermore, good image quality is necessary, something that is often lacking in an elderly heart failure population,[44 45] as shown in the present study. The technique of measuring atrioventricular plane displacement, however, lacks most of the disadvantages associated with traditional echocardiographic techniques, and is well

suited for routine clinical evaluation of left ventricular function.

Assessment of left ventricular systolic function is important not only to evaluate prognosis but also to select patients with proven prognostic benefit from treatment with ACE inhibitors[46-48] and β blockers.[49] A left ventricular ejection fraction of 0·35, a cut off value commonly used in heart failure mortality studies to select patients,[18 46 47 49] corresponds to an atrioventricular plane displacement 7·3 mm. Determination of atrioventricular plane displacement could thus be used as a simple tool to select patients who could benefit from ACE inhibitor treatment. Although one year mortality was substantially higher in our patients with an atrioventricular plane displacement ≤ 7·3 mm than in the patients in the SOLVD treatment trial (left ventricular ejection fraction ≤ 35),[46] this mortality difference does not contradict the finding that a displacement ≤ 7·3 mm selects patients at the same mortality risk as a left ventricular ejection fraction ≤ 0·35. The mortality difference is presumably explained by the facts that our patients were older (mean age 76 years compared with 61 years), although similar with respect to NYHA class, and were included into the study following a period of deterioration of heart failure, whereas patients in the SOLVD study were clinically stable when included.

As with left ventricular ejection fraction, left ventricular atrioventricular plane displacement was not related to NYHA class.[50] With the exception of the presence of a third heart sound—information on which was available only in a minority of our patients—there were no associations between the various clinical assessments and atrioventricular plane displacement. This is in accordance with previous reports on the lack of an association between clinical signs of heart failure and left ventricular ejection fraction.[51]

STUDY LIMITATIONS
The patients in this study were included on the basis of a clinical diagnosis of heart failure. Various criteria have been used in different clinical studies. Since in order to be eligible a patient had to be judged to have heart failure by the treating physician, taking into account the whole picture of symptoms and signs of heart failure, it is unlikely that patients without heart failure were included, despite the fact that patients only had to fulfil one of the objective inclusion criteria in order to be entered into our study. Furthermore, at the one year follow up all surviving patients were still diagnosed as having heart failure by the treating cardiologist.

The mean age of our patients was 76 years, and our results may not be applicable to younger heart failure patients. However, since the majority of heart failure patients are elderly, our study population is representative of most such patients.

The difference in prognosis between the atrioventricular plane displacement groups could have been influenced by drug treatment. However, neither at baseline nor at the one year follow up visit were there any differences between displacement groups regarding treatments known to affect prognosis in heart failure, that is, ACE inhibitors and β blockers.

CONCLUSIONS
The technique of measuring atrioventricular plane displacement is readily mastered and lacks most of the disadvantages associated with traditional echocardiographic techniques. Since atrioventricular plane displacement was closely related to mortality in heart failure patients we recommend this technique for general use. Further investigation is warranted to assess the change in atrioventricular plane displacement over time, the effects of different drugs on the displacement, and also to validate the usefulness of determining atrioventricular plane displacement in clinical practice and as a screening tool in clinical studies.

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